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FORM PTO-1390 (REV. 12-2001)		U.S. DEPARTMENT OF COMMERCE PATENT AND TRADEMARK OFFICE		ATTORNEY'S DOCKET NUMBER 21.0886	
<b>TRANSMITTAL LETTER TO THE UNITED STATES DESIGNATED/ELECTED OFFICE (DO/EO/US) CONCERNING A FILING UNDER 35 U.S.C. 371</b>				U.S. APPLICATION NO. (If known, see 37 CFR 1.5) <div style="font-size: 1.5em; font-weight: bold;">10/031476</div>	
INTERNATIONAL APPLICATION NO. PCT/EP00/07284		INTERNATIONAL FILING DATE 25 Jul 00 (25.07.00)		PRIORITY DATE CLAIMED 5 Aug 99 (05.08.99)	
TITLE OF INVENTION A METHOD OF DETERMINING PARAMETERS OF FORMATIONS THROUGH WHICH A BOREHOLE PASSES					
APPLICANT(S) FOR DO/EO/US LEGENDRE, Emmanuel and SMITS, Jan W.					
Applicant herewith submits to the United States Designated/Elected Office (DO/EO/US) the following items and other information:					
1. <input checked="" type="checkbox"/> This is a <b>FIRST</b> submission of items concerning a filing under 35 U.S.C. 371. 2. <input type="checkbox"/> This is a <b>SECOND</b> or <b>SUBSEQUENT</b> submission of items concerning a filing under 35 U.S.C. 371. 3. <input checked="" type="checkbox"/> This is an express request to begin national examination procedures (35 U.S.C. 371(f)). The submission must include items (5), (6), (9) and (21) indicated below. 4. <input type="checkbox"/> The US has been elected by the expiration of 19 months from the priority date (Article 31). 5. <input checked="" type="checkbox"/> A copy of the International Application as filed (35 U.S.C. 371(c)(2)) a. <input checked="" type="checkbox"/> is attached hereto (required only if not communicated by the International Bureau). b. <input checked="" type="checkbox"/> has been communicated by the International Bureau. c. <input type="checkbox"/> is not required, as the application was filed in the United States Receiving Office (RO/US). 6. <input type="checkbox"/> An English language translation of the International Application as filed (35 U.S.C. 371(c)(2)). a. <input type="checkbox"/> is attached hereto. b. <input type="checkbox"/> has been previously submitted under 35 U.S.C. 154(d)(4). 7. <input type="checkbox"/> Amendments to the claims of the International Application under PCT Article 19 (35 U.S.C. 371(c)(3)) a. <input type="checkbox"/> are attached hereto (required only if not communicated by the International Bureau). b. <input type="checkbox"/> have been communicated by the International Bureau. c. <input type="checkbox"/> have not been made; however, the time limit for making such amendments has NOT expired. d. <input type="checkbox"/> have not been made and will not be made. 8. <input type="checkbox"/> An English language translation of the amendments to the claims under PCT Article 19 (35 U.S.C. 371 (c)(3)). 9. <input type="checkbox"/> An oath or declaration of the inventor(s) (35 U.S.C. 371(c)(4)). 10. <input type="checkbox"/> An English language translation of the annexes of the International Preliminary Examination Report under PCT Article 36 (35 U.S.C. 371(c)(5)).					
Items 11 to 20 below concern document(s) or information included:					
11. <input type="checkbox"/> An Information Disclosure Statement under 37 CFR 1.97 and 1.98. 12. <input checked="" type="checkbox"/> An assignment document for recording. A separate cover sheet in compliance with 37 CFR 3.28 and 3.21 is included. 13. <input checked="" type="checkbox"/> A FIRST preliminary amendment. 14. <input type="checkbox"/> A SECOND or SUBSEQUENT preliminary amendment. 15. <input type="checkbox"/> A substitute specification. 16. <input type="checkbox"/> A change of power of attorney and/or address letter. 17. <input type="checkbox"/> A computer-readable form of the sequence listing in accordance with PCT Rule 13ter.2 and 35 U.S.C. 1.821 - 1.825. 18. <input type="checkbox"/> A second copy of the published international application under 35 U.S.C. 154(d)(4). 19. <input type="checkbox"/> A second copy of the English language translation of the international application under 35 U.S.C. 154(d)(4). 20. <input checked="" type="checkbox"/> Other items or information:					
<div style="margin-left: 300px;">           1) Patent Application            2) PCT International Preliminary Examination Report            3) PCT/IB/308            4) Sheets 1/2 and 2/2 Figures         </div>					

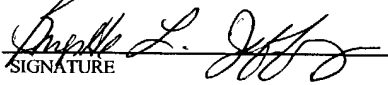
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*Pam Rahmatlo*

U.S. APPLICATION NO. (if known) <b>10/031476</b>		INTERNATIONAL APPLICATION NO. <b>PCT/EP00/07284</b>		ATTORNEY'S DOCKET NUMBER <b>21,0886</b>	
21. <input checked="" type="checkbox"/> The following fees are submitted: <b>BASIC NATIONAL FEE (37 CFR 1.492 (a) (1) - (5)):</b> Neither international preliminary examination fee (37 CFR 1.482) nor international search fee (37 CFR 1.445(a)(2)) paid to USPTO and International Search Report not prepared by the EPO or JPO. . . . . <b>\$1040.00</b>  International preliminary examination fee (37 CFR 1.482) not paid to USPTO but International Search Report prepared by the EPO or JPO . . . . . <b>\$890.00</b>  International preliminary examination fee (37 CFR 1.482) not paid to USPTO but international search fee (37 CFR 1.445(a)(2)) paid to USPTO . . . . . <b>\$740.00</b>  International preliminary examination fee (37 CFR 1.482) paid to USPTO but all claims did not satisfy provisions of PCT Article 33(1)-(4) . . . . . <b>\$710.00</b>  International preliminary examination fee (37 CFR 1.482) paid to USPTO and all claims satisfied provisions of PCT Article 33(1)-(4) . . . . . <b>\$100.00</b> <b>ENTER APPROPRIATE BASIC FEE AMOUNT =</b>				<b>CALCULATIONS PTO USE ONLY</b>	
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CLAIMS	NUMBER FILED	NUMBER EXTRA	RATE		
Total claims	18 - 20 =	0	x <b>\$18.00</b>		
Independent claims	2 - 3 =	0	x <b>\$84.00</b>		
MULTIPLE DEPENDENT CLAIM(S) (if applicable)				+ <b>\$280.00</b>	
<b>TOTAL OF ABOVE CALCULATIONS =</b>				<b>\$ 890</b>	
<input type="checkbox"/> Applicant claims small entity status. See 37 CFR 1.27. The fees indicated above are reduced by 1/2.					
<b>SUBTOTAL =</b>				<b>\$ 890</b>	
Processing fee of <b>\$130.00</b> for furnishing the English translation later than <input type="checkbox"/> 20 <input type="checkbox"/> 30 months from the earliest claimed priority date (37 CFR 1.492(f)).					
<b>TOTAL NATIONAL FEE =</b>				<b>\$ 890</b>	
Fee for recording the enclosed assignment (37 CFR 1.21(h)). The assignment must be accompanied by an appropriate cover sheet (37 CFR 3.28, 3.31). <b>\$40.00</b> per property +					
<b>TOTAL FEES ENCLOSED =</b>				<b>\$ 890</b>	
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a. <input type="checkbox"/> A check in the amount of \$ _____ to cover the above fees is enclosed. b. <input checked="" type="checkbox"/> Please charge my Deposit Account No. <u>19-0610</u> in the amount of \$ <u>890</u> to cover the above fees. A duplicate copy of this sheet is enclosed. c. <input checked="" type="checkbox"/> The Commissioner is hereby authorized to charge any additional fees which may be required, or credit any overpayment to Deposit Account No. <u>19-0610</u> A duplicate copy of this sheet is enclosed. d. <input type="checkbox"/> Fees are to be charged to a credit card. <b>WARNING:</b> Information on this form may become public. <b>Credit card information should not be included on this form.</b> Provide credit card information and authorization on PTO-2038.					
<b>NOTE: Where an appropriate time limit under 37 CFR 1.494 or 1.495 has not been met, a petition to revive (37 CFR 1.137 (a) or (b)) must be filed and granted to restore the application to pending status.</b>  SEND ALL CORRESPONDENCE TO: Brigitte L. Jeffery, IP Counsel Schlumberger Technology Corporation 200 Gillingham Lane, MD 200-9 Sugar Land, TX 77478 USA Tel: (281) 285-7067 Fax: (281) 285-4232					
				 SIGNATURE	
				<u>Brigitte L. Jeffery</u> NAME	
				<u>38,925</u> REGISTRATION NUMBER	

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

**In re Application of:** )  
Emmanuel Legendre et al. ) **Attorney Docket No.:** 21.0886  
**Serial No.:** ) **Group Art Unit:**  
**Filed:** ) **Examiner:**  
**Title:** A METHOD OF DETERMINING PARAMETERS )  
OF FORMATIONS THROUGH WHICH A BOREHOLE )  
PASSES

**PRELIMINARY AMENDMENT**

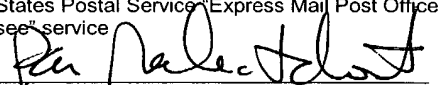
Assistant Commissioner for Patents  
Washington DC 20231

Dear Sir:

Prior to examining the present application, the Applicant requests that the Examiner enter the following amendment:

**In The Claims:**

Please cancel claims 1-14.

"EXPRESS MAIL" Mail Mailing Label	EV
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I hereby certify that this paper is being deposited with the United States Postal Service "Express Mail Post Office to Addressee" service	
	
Pam Rahmatdoost	

Please add the following claims:

- 15 A method of determining parameters of formations through which a borehole passes, on the basis of a resistivity log recorded in the borehole by means of a measuring and recording tool, the method comprising the steps of:
- (i) determining the formation parameters by a quasi-Newton parameter inversion method implemented on pseudo-parameters that are homogeneous and that are determined from the formation parameters so as to obtain a model of the formations;
  - (ii) calculating the response of the tool to the model;
  - (iii) using a comparison criterion for comparing the calculated response with the recorded log;
  - (iv) performing at least one new iteration if the comparison criterion is not satisfied; and
  - (v) determining the formation parameters from the calculated response.
- 16 A method as claimed in claim 15, further comprising determining boundaries between geological beds prior to implementing the quasi-Newton method.
- 17 A method as claimed in claim 16, further comprising determining the bed boundaries on the basis of points of inflection in log data.
- 18 A method as claimed in claim 16, further comprising selecting a bed model for each geological bed prior to implementing the quasi-Newton method.
- 19 A method as claimed in claim 18, wherein the bed model comprises parameters concerning distance from the borehole axis so as to define radial zones about the axis, and a resistivity parameter within each radial zone defined in this manner.
- 20 A method as claimed in claim 15, further comprising selecting observable magnitudes.

- 21 A method as claimed in claim 20, wherein selecting the observable magnitudes includes defining a combination of data items from the log.
- 22 A method as claimed in claim 18, further comprising selecting observable magnitudes and giving each observable magnitude a value for each geological bed.
- 23 A method as claimed in claim 22, wherein the step of giving each observable magnitude a value for each geological bed comprises interpolating, within each layer, values of the observable magnitude as determined within each bed.
- 24 A method as claimed in claim 22, wherein each observable magnitude is given a value for each geological bed by giving the observable magnitude the value it possesses at a measurement point closest to the middle of the bed.
- 25 A method as claimed in claim 15, wherein the step of determining parameters from log data by a quasi-Newton method is performed by estimating the Jacobian of the problem by Broyden's method.
- 26 A method as claimed in claim 15, wherein the log used is an  $R_{LLS}$  and  $R_{LLd}$  log.
- 27 A method as claimed in claim 15, wherein the log used is an  $R_{LA1}$ , ...,  $R_{LA5}$  log.
- 28 A method of determining the parameters  $R_t$ ,  $R_{x0}$ , and  $d_i$  of formations through which a borehole passes, on the basis of a resistivity log recorded in the borehole by means of a measuring and recording tool, the method comprising the steps of:
  - (i) determining the formation parameters by a quasi-Newton parameter inversion method implemented on pseudo-parameters that are homogeneous and that are determined from the formation parameters so as to obtain a model of the formations;
  - (ii) calculating the response of the tool to the model;

- (iii) using a comparison criterion for comparing the calculated response with the recorded log;
- (iv) performing at least one new iteration if the comparison criterion is not satisfied; and
- (v) determining the parameters  $R_t$ ,  $R_{x0}$ , and  $d_i$  from the calculated response.

- 29 A method as claimed in claim 28, further comprising determining boundaries between geological beds prior to implementing the quasi-Newton method.
- 30 A method as claimed in claim 29, further comprising determining the bed boundaries on the basis of points of inflection in log data.
- 31 A method as claimed in claim 29, further comprising selecting a bed model for each geological bed prior to implementing the quasi-Newton method.
- 32 A method as claimed in claim 31, wherein the bed model comprises parameters concerning distance from the borehole axis so as to define radial zones about the axis, and a resistivity parameter within each radial zone defined in this manner.
- 33 A method as claimed in claim 28, further comprising selecting observable magnitudes.
- 34 A method as claimed in claim 33, wherein selecting the observable magnitudes includes defining a combination of data items from the log.
- 35 A method as claimed in claim 31, further comprising selecting observable magnitudes and giving each observable magnitude a value for each geological bed.
- 36 A method as claimed in claim 35, wherein the step of giving each observable magnitude a value for each geological bed comprises interpolating, within each layer, values of the observable magnitude as determined within each bed.

- 37 A method as claimed in claim 35, wherein each observable magnitude is given a value for each geological bed by giving the observable magnitude the value it possesses at a measurement point closest to the middle of the bed.
- 38 A method as claimed in claim 28, wherein the step of determining parameters from log data by a quasi-Newton method is performed by estimating the Jacobian of the problem by Broyden's method.
- 39 A method as claimed in claim 28, wherein the log used is an  $R_{LLs}$  and  $R_{LLd}$  log.
- 40 A method as claimed in claim 28, wherein the log used is an  $R_{LA1}$ , ...,  $R_{LA5}$  log.

Respectfully submitted,

Date: 16 January 2002

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## A METHOD OF DETERMINING PARAMETERS OF FORMATIONS THROUGH WHICH A BOREHOLE PASSES

The present invention relates to a method of determining parameters of  
5 formations through which a borehole passes, and more particularly to such a method  
of determining parameters on the basis of a resistivity log recorded in said borehole by  
means of a measuring and recording tool, said method comprising the steps consisting  
in:

- determining said formation parameters by a parameter inversion method so as to  
10 obtain a model of the formations;
- calculating the response of said tool to said model;
- using a comparison criterion for comparing said calculated response with said  
recorded log; and
- performing at least one new iteration if said comparison criterion is not satisfied.

15 Such methods are known. In general, they are implemented after a first stage  
of initializing parameters.

It is well known to make resistivity logs in boreholes by means of tools  
designed to measure the resistivity of the formations through which the borehole  
passes by establishing galvanic currents or eddy currents in the formations around the  
20 tool. Such tools give a set of resistivity values at each of the depths at which  
measurements are performed, the values applying to various distances from the axis of  
the borehole.

The relationship between the resistivity measurements performed in this way  
and the actual characteristics of the formations through which the borehole passes are  
25 typically affected by three types of effect:

a) the hole effect due to the presence of the borehole, which is generally filled  
with a drilling mud that is much more conductive than the formations;

b) the shoulder bed effect due to the presence of generally heterogeneous  
formations above and below the zone being investigated, which formations can  
30 perfectly well have greater conductivity or greater resistivity than the formations level  
with the apparatus (it should be observed that the shoulder bed effect can be  
considerable even if the sonde is completely contained within a homogeneous bed  
surrounded by formations of different resistivities); and

c) the invasion effect due to the presence of drilling mud filtrate in the vicinity  
35 of the borehole, where the filtrate has replaced some of the fluids that were initially  
present in the formations.



To a first approximation, the invaded zone is represented by a region extending between the borehole and a cylinder of diameter  $d_i$  that is coaxial with the borehole and that has radially uniform resistivity  $R_{x0}$ , and beyond which a virgin zone of resistivity  $R_t$  is to be found. That model has three unknowns:  $R_t$ ,  $R_{x0}$ , and  $d_i$ , which is why at least three measurements having different radial investigation depths are recorded simultaneously so as to be able to determine the three unknowns.

The problem thus consists in determining at each depth a set of geometrical and electrical parameters, for example in this case the invasion diameter  $d_i$  and the resistivity  $R_{x0}$  of the invaded zone and the resistivity  $R_t$  of the virgin zones, on the basis of a set of resistivity measurements performed at depths that are separated by a given measurement pitch, the resistivities measured at each depth each being characteristic of the resistivity of the formation at a certain distance from the axis of the borehole.

Various methods are known that are capable of resolving that problem. Such methods are essentially of three types.

A first type of known method makes use of deconvolution filters. That approach assumes that the observed signal is the result of convolution between the real distribution of resistivities and a filter which represents the response of the tool to a resistivity distribution (or a conductivity distribution if the convolution is performed on the basis of a conductivity distribution). The method of interpretation then consists in deconvoluting the observed log by means of a known filter so as to discover the resistivity distribution. This step corresponds to correcting the initial data for shoulder bed effects.

This step is preceded or followed by a radial correction step seeking to correct for the results of the invasion effect.

The convolution filter can also be estimated by calculating the response of the tool to a formation possessing a resistivity distribution close to reality, which corresponds to local linearization of the filter.

Methods of that type are limited by the fact that the corrections performed therein for the shoulder bed effect and for the invasion effect are assumed to be independent whereas in reality they cannot, in general, be separated.

Another type of known method consists in partitioning the formation into cells.

Attempts are then made to obtain an image of the formation in terms of resistivity. The formation is partitioned into cells (usually in rectangle following the borehole axis and perpendicular to that axis), and a resistivity value is defined for each cell. A calculation algorithm is then used, e.g. using finite elements, finite differences, or a neural network, to calculate the response of the tool to the formations modelled in

this way, so as to determine whether the assumed resistivity distribution explains the apparent resistivity.

The horizontal boundaries of the cells can be determined by a segmentation algorithm and the vertical boundaries are often fixed by the user. In general, the use of cells of large size leads to poor definition and thus to a poor approximation to reality, while the use of small cells can lead to instability which requires constraints to be fixed concerning the suddenness with which resistivity can vary, and such constraints deform the solution.

The unknowns of the inverse problem which are electrical unknowns only, are in this case the resistivities of the various cells. These resistivities present a large number of degrees of freedom, that can lead to the above-mentioned instability. As mentioned above, one way of resolving such instability problems consists in imposing constraints, however such constraints suffer from the drawback of falsifying the solution.

The problem is easier to resolve when the number of resistivities describing a layer or bed is relatively small. However, under such circumstances, the model of the formation is less accurate. A bed split into a small number of radial zones does not accurately approximate the more realistic piston-profile model ( $R_{x0}$ ,  $d_t$ , and  $R_t$ ). This model insufficiency introduces a systematic bias into the inversion process.

A third type of known method consists in performing parametric local inversion. The general idea on which this approach is based is to use Newton's method to invert all of the unknown parameters describing the formation, such as the positions of the bed boundaries, and the values of  $d_i$ ,  $R_{x0}$ , and  $R_t$ , i.e. in this case the geometrical and resistivity parameters. In order to obtain a large enough number of observable magnitudes, several readings of the tool near the area inverted can be used. A criterion – for instance a quadratic criterion – for evaluating error between observable magnitudes and reconstituted reading is minimized.

The advantage of that method is its flexibility. A wide variety of formation models can be used and there is a large amount of freedom in selecting input measurements.

However, because of the generality of that approach, the inverse problem is often highly non-linear. Consequently, only local inversion can be performed and accurate gradients must be estimated, which is extremely expensive in terms of computation time.

Furthermore, when the method is used on real logging data, instabilities are observed which are the result of the local nature of the inversion.

The present invention seeks to mitigate those drawbacks.

To this end, the invention provides a method of determining parameters of formations through which a borehole passes, on the basis of a resistivity log recorded in said borehole by means of a measuring and recording tool, the method comprising the steps consisting in determining said formation parameters by a parameter inversion  
 5 method so as to obtain a model of the formations; calculating the response of said tool to said model; using a comparison criterion for comparing said calculated response with said recorded log; and performing at least one new iteration if said comparison criterion is not satisfied; said method being characterized by the fact that the step of determining said parameters from log data is performed by a quasi-Newton method;  
 10 and said quasi-Newton method is implemented on pseudo-parameters that are homogeneous and that are determined from said formation parameters.

The method of the invention assumes that the boundaries between the layers (beds) are known.

In addition, any method known in the prior art is used for reconstituting the  
 15 response of the tool to a given description of the formation (direct model).

For each bed, a bed model can be selected as being the most realistic. One particular bed model is a partition of the bed into various radial zones each of which possesses contact resistivity. In each bed, some of the parameters can be selected as being the unknowns of the inverse problem. Both resistivity and the positions of the  
 20 radial interfaces constitute possible unknowns.

A certain number of "observables" are associated with each bed. An "observable" is a measurement made by the tool which is considered to be a function of the unknowns of the bed. For example, if the tool gives two measurements at each depth, the two measurements obtained close to the middle of the bed can be selected  
 25 as being a function of two parameters of the bed model.

The observables can be the result of the same kind of measurement, but taken at different depths or with the tool in different positions. The rule for selecting observables depends on the tool and on the model that is to be inverted. The generality of the method of the invention makes inversion possible with a wide  
 30 selection of observables.

Consequently, the invention is based on local methods of parametric inversion. Nevertheless, optimization is now performed that is not local, i.e. that takes place simultaneously over all of the layers.

The hole effect is obviated by assuming that the resistivity of the mud is  
 35 known and also that the diameter of the borehole is known. In addition, the positions of the horizontal boundaries between the beds are known, e.g. from zero crossings of the second derivative of conductivity.

It is also assumed that the resistivity values at certain radial depths are known, e.g. the resistivities  $R_{LLs}$  and  $R_{LLd}$ , or other radial distributions of resistivity.

The unknowns at each depth are  $R_{x0}$ ,  $R_t$ , and  $d_i$ .

If it is desired to determine specifically  $R_{x0}$ , then it is necessary to know the microresistivity, assuming that the measured values are  $R_{LLs}$  and  $R_{LLd}$ .

In any event, it is necessary in theory for the number of unknowns to be smaller than the number of observables. In practice, the method of the invention requires that the number of unknowns be equal to the number of observables. When the number of observables is greater than the number of unknowns, either no account is taken of some of the observables, or else combinations of observables are taken as unknowns.

The invention thus consists essentially in:

- firstly applying a quasi-Newton method to the problem of parametric inversion; and
- secondly improving convergence in a quasi-Newton method which is generally affected by combining geometrical parameters such as  $d_i$  and electrical parameters such as  $R_{x0}$  and  $R_t$ , by using combinations of such geometrical and electrical parameters as the unknowns, e.g. combinations that all consist in pseudo-electrical magnitudes, and in particular pseudo-resistivities.

Consequently, two transformations are generally performed when implementing the invention.

A first transformation is generally performed in the observables space so as to reduce the number of observables to the number of unknowns. This is necessary in order to be able to apply the inversion algorithm which assumes that the number of observables is equal to the number of unknowns.

The second transformation is performed in the unknowns space to obtain a set of unknowns that are homogeneous, in particular that are electrical, on the basis of unknowns that are not homogeneous, e.g. unknowns that are geometrical and unknowns that are electrical.

A particular implementation of the invention is described below by way of non-limiting example and with reference to the accompanying diagrammatic drawings, in which:

- Figure 1 is an overall flow chart of a method of the invention; and
- Figure 2 is a flow chart of an iteration of the calculation algorithm.

As shown in Figure 1, implementation of the method of the invention begins by a step 1 of measuring various physical magnitudes of the formation from inside a borehole. At each measurement level, the number of magnitudes measured in this way

must be not less than the number of parameters for which it is desired to obtain a value at each level.

By way of example, in the common case where the parameters that it is desired to determine are the resistivity values  $R_{x0}$  and  $R_t$ , and also the invasion distance  $d_i$ , making a total of three parameters, at least three magnitudes will be measured at each step.

By way of example, it is possible to measure the magnitudes  $R_{LLs}$  and  $R_{LLd}$  by means of a tool known as a Dual Laterolog (Schlumberger registered trademark) and to measure  $R_{x0}$  directly by means of a device known as an MSFL (Schlumberger trademark for "micro spherically focused log"). In another implementation of this step of the method, it is possible to measure the resistivities  $R_{LAI}$ , ...,  $R_{LA5}$  obtained by means of a device known as an HRLA (Schlumberger trademark for: "high resolution laterolog array"), which correspond to formation resistivities as measured at increasing distances from the axis of the borehole.

Following step 2 consists in determining the locations of the beds or layers whose parameters are to be determined. The locations of the beds can be determined automatically by means of a segmentation algorithm of known type, e.g. based on looking for points of inflection in the apparent conductivity values.

During this step, a first initialization value is given to each parameter.

Following step 3 consists in selecting the appropriate number of "observable" magnitudes. Remaining in the context where it is desired that  $R_{x0}$ ,  $R_t$ , and  $d_i$  should be determined, the observables used will be the three measurements obtained by means of the dual laterolog and the MSFL, in the first case.

In the second case where measurements are made using the HRLA, one or two of the values  $R_{LAI}$ , ...,  $R_{LA5}$  can be eliminated and/or three observables can be obtained by combining these values, in particular by combining them in linear manner.

During following step 4, a value is given to each observable for each determined layer, as mentioned above.

It will be observed that more measurement steps are available than there are layers since it is necessary in particular to have at least three measurement steps in order to be able to determine a point of inflection.

For this purpose, it is possible to interpolate the measurements performed within a layer so as to obtain the value of each of the observables in the middle of the layer.

It is also possible to give each layer the values of the observables as measured at the measurement point that its closest to the middle of the layer.

The following step 5 consists in determining the looked-for parameters.

Mathematically, the problem is thus posed as follows.

This problem is the inverse of the direct problem in which it is desired to determine the response of the measurement tools, the observables of the problem of the invention, from the actual parameters of the formation, i.e. the unknowns in the problem of the invention.

We use the notation:

$f(U)=O$  for the direct problem; and

$U=f^{-1}(O)$  for the problem of the invention, i.e. the inverse of the direct problem.

The direct problem can be resolved, i.e. the system of non-linear equations  $f_i$  can be evaluated as a function of the layer model and of previously selected observables. By way of example, when the physical characteristics under consideration are resistivities, the layer model consists in defining how the resistivity of the terrain varies as a function of distance from the axis of the borehole, or indeed the  $R_{x0}$ ,  $R_t$ , and  $d_i$  model.

To solve the inverse problem, it is necessary to use an iterative method, i.e. to determine a stream of values  $U_1, U_2, \dots, U_\infty$  tending towards the solution  $U_{\text{solution}}$ , such that:

$$f(U_{\text{solution}}) = O_{\text{observed}}$$

In conventional methods, a term  $U_+$  of the above stream is obtained from the current term  $U_c$  using the following equation:

$$(1) \quad U_+ = U_c - (\nabla f)^{-1} * [f(U_c) - O_{\text{observed}}]$$

where  $\nabla f$  is the Jacobian of the function  $f(U)$ .

It is recalled that the Jacobian of the function  $f$  is defined as follows:

$$\text{If } f: \mathcal{R}^N \rightarrow \mathcal{R}^N$$

$$\text{then } \nabla f: \mathcal{R}^{N \times N} \rightarrow \mathcal{R}^{N \times N}$$

$$\text{with } (\nabla f)_{i,j} = \frac{\partial f_i}{\partial u_j}$$

It can thus be seen that a large number of evaluations of the function  $f$  is required to estimate the  $N \times N$  matrix, given that the system of equations can typically have 1000 observables and 1000 unknowns.

According to the invention, instead of using Newton's method in which, on each iteration, a new vector  $U$  is estimated and a new Jacobian is calculated, a quasi-Newton method is used in which both the vector  $U$  and the Jacobian are estimated at each step. If the current estimate of the Jacobian is  $B_c$ , then equation (1) is replaced by:

$$(2) \quad U_+ = U_c - B_c^{-1} * [f(U_c) - O_{\text{observed}}]$$

A new estimate of the Jacobian can be obtained on each iteration, for example, using the Broyden method as described at pages 113 to 131 of "Iterative method for linear and non-linear equations" by C.T. Kelley published by Society for Industrial and Applied Mathematics.

More precisely, the matrix  $B_+^{-1}$  at the following step is obtained from the current matrix  $B_c^{-1}$  using the following equation:

$$(3) \quad B_+^{-1} = B_c^{-1} * \left( I + \frac{[f(U_c) - O_{\text{observed}}] * s^T}{s^T * s} \right)$$

where  $I$  is the identity matrix and where  $s = U_+ - U_c$ .

With this method, it is therefore no longer necessary to know the Jacobian.

Nevertheless, to ensure that the stream of  $B_n^{-1}$  converges quickly, the initial data is preconditioned so as to be homogeneous. In the present case, this is achieved not by using the variables  $R_{x0}$ ,  $R_t$ , and  $d_i$ , which are not homogeneous, given the presence of  $d_i$ , but by using the resistivities  $R_{x0}$  and  $R_t$ , together with the pseudo-resistivity  $R_a$  as defined by:

$$(4) \quad \begin{cases} R_a = \alpha * R_{x0} + (1 - \alpha) * R_i \\ \alpha = \frac{d_{imax} - d_i}{d_{imax} - d_{imin}} \end{cases}$$

where  $d_{imax}$  and  $d_{imin}$  are parameters fixed so as to correspond to maximum and minimum acceptable values for  $d_i$ .

Figure 2 is a complete flow chart for one interaction.

For example, the starting point is an identity matrix, and at 11, an iteration of the above-described quasi-Newton method is applied to obtain pseudo-resistivities  $R_1$ ,  $R_2$ , and  $R_3$  for each layer, as shown at 12.

The pseudo-resistivities  $R_1$ ,  $R_2$  and  $R_3$  are then transformed at 13 into physical magnitudes 14:  $R_{x0}$ ,  $R_t$ , and  $d_i$ .

It is then possible at 15 to update each layer of the model of the formation so as to obtain a formation model 16 which is updated in terms of  $R_{x0}$ ,  $R_t$  and  $d_i$ .

The response of the tool to the formation 16 is then calculated at 17 in conventional manner, e.g. by a finite element method, so as to obtain a simulated log 18.

- 5 In step 19, the simulated log is compared with a real log 20. If the difference between the simulated log and the real log satisfies a predetermined criterion, the iteration terminates at 21. Otherwise, a new iteration is performed.



## CLAIMS

1. A method of determining parameters of formations through which a borehole passes, on the basis of a resistivity log (20) recorded in said borehole by means of a measuring and recording tool, the method comprising the steps consisting in:

- 5     • determining said formation parameters by a parameter inversion method (11) so as to obtain a model of the formations;
- calculating the response of said tool to said model;
- using a comparison criterion for comparing said calculated response with said recorded log; and
- 10    • performing at least one new iteration if said comparison criterion is not satisfied; said method being characterized by the fact that:
  - said parameter inversion is performed using a quasi-Newton method; and
  - said quasi-Newton method is implemented on pseudo-parameters (12) that are homogeneous and that are determined from said formation parameters.

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2/ A method according to claim 1, including a step of determining the boundaries between geological beds, prior to implementing said quasi-Newton method.

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3/ A method according to claim 2, in which the bed boundaries are determined on the basis of points of inflection in the log data.

25

4/ A method according to any one of claims 1 to 3, comprising a step of selecting a bed model for each geological layer, prior to implementing said quasi-Newton method.

5/ A method according to claim 4, in which the bed model is constituted by parameters concerning distance from the borehole axis so as to define radial zones about said axis, and a resistivity parameter within each radial zone as defined in this way.

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6/ A method according to any one of claims 1 to 5, including a step of selecting observable magnitudes.

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7/ A method according to claim 6, in which selecting the observable magnitudes includes defining a combination of data items from the log.

8/ A method according to claims 4 and 6 together, comprising a step of giving each observable a value for each geological bed.

9/ A method according to claim 8, in which the step of giving each observable a value for each geological bed comprises interpolating, within each layer, values of the observable as determined within each bed.

5

10/ A method according to claim 8, in which each observable is given a value for each geological bed by giving said observable the value it possesses at the measurement point closest to the middle of the bed.

10 11/ A method according to any one of claims 1 to 10, in which the step of determining said parameters from log data by a quasi-Newton method is performed by estimating the Jacobian of the problem by Broyden's method.

12/ A method according to any one of claims 1 to 11, in which the log used is the  
15  $R_{LLs}$  and  $R_{LLd}$  log.

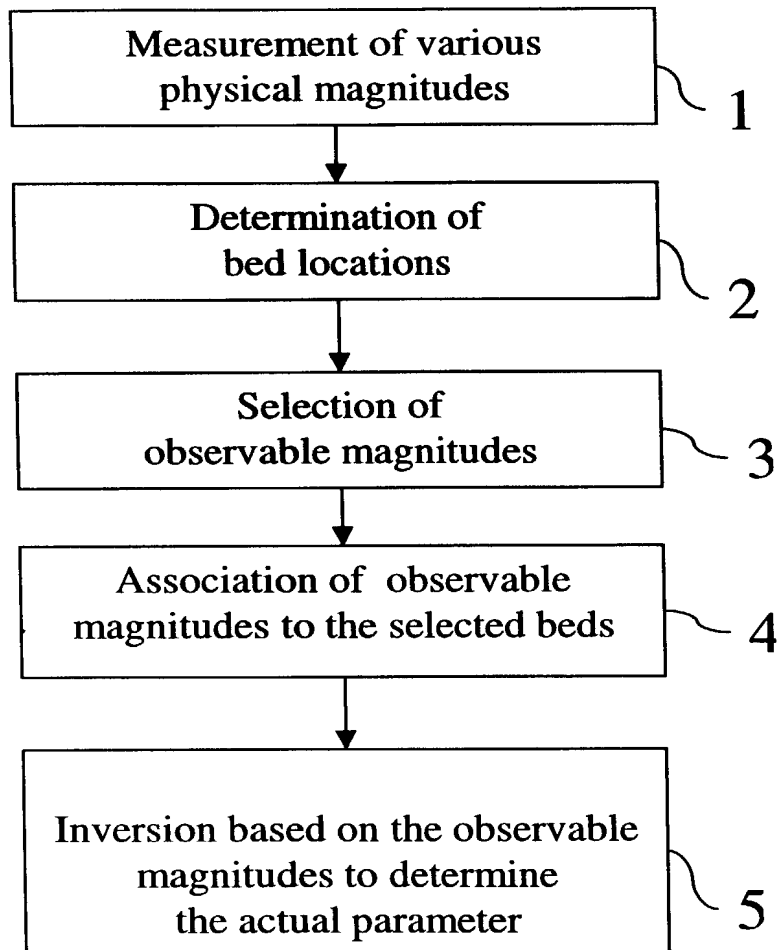
13/ A method according to any one of claims 1 to 11, in which the log used is the  $R_{LA1}$ , ...,  $R_{LA5}$  log.

20 14/ The use of the method according to any one of claims 1 to 13 in determining the parameters  $R_f$ ,  $R_{x0}$ , and  $d_i$ .

## ABSTRACT

The invention relates to a method of determining parameters of formations through which a borehole passes, on the basis of a resistivity log (20) recorded in said borehole by means of a measuring and recording tool, the method comprising the steps  
5 consisting in determining said formation parameters by a parameter inversion method so as to obtain a model of the formations; calculating the response of said tool to said model; using a comparison criterion for comparing said calculated response with said recorded log; and performing at least one new iteration if said comparison criterion is  
10 not satisfied; the method being characterized by the fact that the inversion is performed by a quasi-Newton method implemented on pseudo-parameters that are homogeneous and that are determined from said formation parameters.

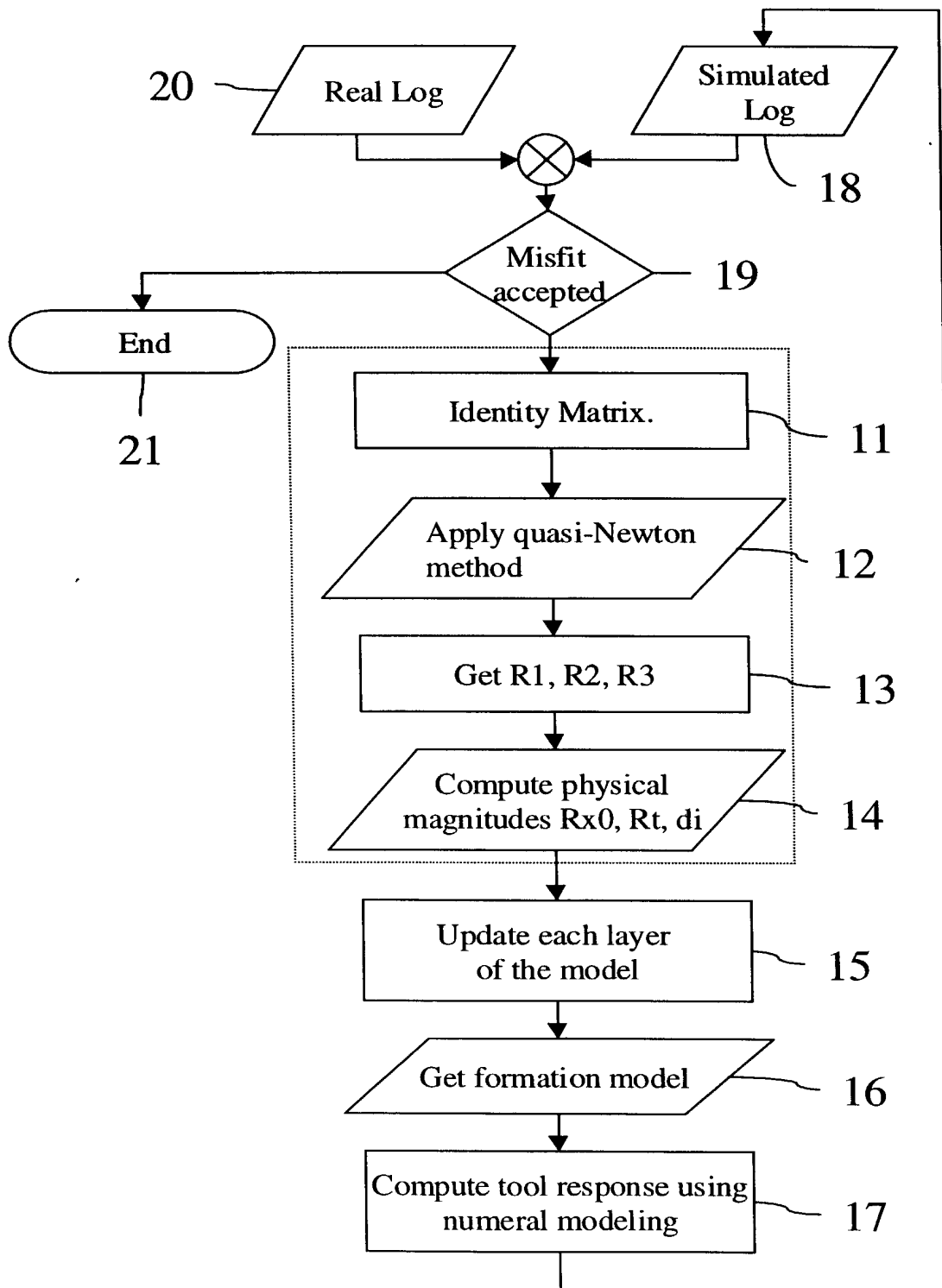
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**FIGURE 1**

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FIGURE 2



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## DECLARATION FOR PATENT APPLICATION AND POWER OF ATTORNEY

As a below named inventor, I hereby declare that:

My residence, post office address and citizenship are as stated below next to my name, and

I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled:

### A METHOD OF DETERMINING PARAMETERS OF FORMATIONS THROUGH WHICH A BOREHOLE PASSES

the specification of which

[X] was filed on July , 25<sup>th</sup>, 2000 as PCT International Application Number PCT/EP00/07284

and was amended on (if applicable) \_\_\_\_\_

I hereby state that I have reviewed and understand the contents of the above identified specification, including the claims, as amended by any amendment referred to above.

I acknowledge the duty to disclose information which is material to the examination of this application in accordance with Title 37, Code of Federal Regulations, Section 1.56(a).

I hereby claim foreign priority benefits under Title 35, United States Code, Section 119 of any foreign application(s) for patent or inventor's certificate , or 365(a) of any PCT international application which designated at least one country other than the United States of America, listed below and have also identified below any foreign application for patent or inventor's certificate or of any PCT international application having a filing date before that of the application on which priority is claimed:

Prior Foreign Application(s)

Priority Claimed

99/10178 FR  
(Number) (Country)

05/08/99  
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[X] YES [ ] NO

I hereby claim the benefit under Title 35, United States Code, Section 119(e) of any United States provisional application(s) listed below:

\_\_\_\_\_  
Application No.

\_\_\_\_\_  
Filing Date

\_\_\_\_\_  
Application No.

\_\_\_\_\_  
Filing Date

21.0886

I hereby claim the benefit under Title 35, United States Code, Section 120 of any United States application(s), or 365(c) of any PCT international application designating the United States of America, listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States or PCT international application in the manner provided by the first paragraph of Title 35, United States Code, Section 112, I acknowledge the duty to disclose information which is material to patentability as defined in Title 37, Code of Federal Regulations, Section 1.56 which occurred between the filing date of the prior application and the national or PCT international filing date of this application:

Application  
Serial No.

Filing  
Date

Status-patented, pending,  
abandoned

Application  
Serial No.

Filing  
Date

Status-patented, pending,  
abandoned

As a named inventor, I hereby appoint the following attorney(s) and/or agents(s) to prosecute this application and transact all business in the Patent and Trademark Office connected therewith.

J. J. Ryberg, #31,134; Brigitte L. Jeffery, #38,925; Steven L. Christian, #38,106 and Victor H. Segura, #44,329. I hereby request that all correspondence, notices, official letters and other communication be directed to Schlumberger Technology Corporation, ATTN: IP Counsel, P. O. BOX 2175, Houston, Texas 77252-2175; and that all telephone calls be directed to: Steven L. Christian, at (281) 285 8809, Schlumberger Oilfield Services, P. O. BOX 2175, Houston, Texas 77252-2175. Schlumberger U.S. PTO Customer No. is 23718.

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true, and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

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Signature



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